

# The origin of the compositional diversity of Mercury's surface constrained from experimental melting of enstatite chondrites

A. Boujibar (1), K. Righter (1), K. Pando (2) and L. Danielson (3).

(1) NASA Johnson Space Center, Houston, USA, <sup>2</sup>UTAS – Jacobs JETS Contract, NASA Johnson Space Center, Houston, USA, <sup>3</sup>Jacobs JETS, NASA Johnson Space Center, Houston, USA. (asmaa.boujibar@nasa.gov).

## 1. Introduction

Mercury is known as an endmember planet as it is the most reduced terrestrial planet with the highest core/mantle ratio. MESSENGER spacecraft has shown that its surface is FeO-poor (2-4 wt%) and S-rich (up to 6-7 wt%) [1-2], which confirms the reducing nature of its silicate mantle [3]. Moreover, high resolution images revealed large volcanic plains and abundant pyroclastic deposits [4], suggesting important melting stages of the Mercurian mantle. This interpretation was confirmed by the high crustal thickness (up to 100 km) derived from Mercury's gravity field [5]. This is also corroborated by a recent experimental result that showed that Mercurian partial melts are expected to be highly buoyant within the Mercurian mantle and could have risen from depths as high as the core-mantle boundary [6].

In addition MESSENGER spacecraft provided relatively precise data on major elemental compositions of Mercury's surface [7]. These results revealed important chemical and mineralogical heterogeneities that suggested several stages of differentiation and re-melting processes [8]. However, the extent and nature of compositional variations produced by partial melting remains poorly constrained for the particular compositions of Mercury (very reducing conditions, low FeO-contents and high sulfur-contents). Therefore, in this study, we investigated the processes that lead to the various compositions of Mercury's surface. Melting experiments with bulk Mercury-analogue compositions were performed and compared to the compositions measured by MESSENGER.

## 2. Methods

Experiments were conducted with a piston cylinder apparatus at NASA JSC at 1 GPa and temperatures

between 1400°C and 1650°C, using enstatite chondrites (EH4), with variable oxygen fugacity and sulfur content. By varying the Si/SiO<sub>2</sub> ratio of the starting composition, we could control the  $f_{O_2}$  of the experiments. We used two starting compositions with two different sulfur contents, Si/SiO<sub>2</sub> ratios and oxygen fugacity (see **Table 1**). Experimental run products were analyzed with Cameca and JEOL EPMA at NASA JSC.

## 3. Results

### 3.1 Oxygen fugacity

The oxygen fugacity of the samples was calculated relative to the IW buffer and Si/SiO<sub>2</sub> buffer. The  $f_{O_2}$  was estimated at IW-3 and IW-6 for the composition 1 and composition 2 respectively (see **Table 1**).

### 3.2 Phase proportions

The samples synthesized with the compositions 1 and 2 are both composed of orthopyroxene, silicate melt and liquid metal at high temperature. For composition 1, when T<1450°C, quartz is also present in the samples, while for composition 2, at T<1500°C, a liquid sulfide is also present. However this sulfide phase represents only 1 to 3% of the experimental charges. This is due to sulfur volatilization during the heating of the samples. Indeed mass balance calculations show that at least half the initial content of sulfur was volatilized during sample heating. In addition the samples synthesized with the most S-rich composition are also very reduced, so that S is highly solubilized in the silicate melt (with S-concentrations up to 9 wt%).

### 3.3 Evolution of the silicate melts compositions

Our data are combined with previous experiments performed at 1 bar [9] with EH4 enstatite chondrite [10] as starting composition which is closer to our

synthetic composition 2. Incompatible elements (Na, K, Al, Si) decrease with temperature while compatible elements (Mg) increase with temperature. Major differences between the experiments conducted with the starting composition 1 and 2 are the enrichment in  $\text{SiO}_2$  in the silicate melts with the first composition in comparison to the second one. At 1 bar the presence of large fractions of Ca-rich sulfide significantly affects the behavior of CaO in the silicate melt. At 1 GPa, sulfide is only present in low proportions (<3 wt%), therefore it does not have any effect on the CaO concentration of the silicate melt.

#### 4. Comparison with Mercury's surface:

Ca/Si, Mg/Si and Al/Si element ratios of our silicate melts and that of previous studies [9] are compared to that of Mercury's surface in Fig. 1. We found that the melts produced with composition 1 have lower Al/Si and Ca/Si ratios than Mercury's surface. This can be due to the high  $\text{SiO}_2$  of the starting composition 1. On the other hand, the compositions of Mercury's surface are in a good match with the silicate melts synthesized with the S-rich starting material (this study, composition 2) and the samples run at 1 bar by [9] with EH4 chondrites.

Our results show that melting at various pressures of sulfur-rich EH4 chondrites can generate liquids with a high diversity in chemical composition. The heterogeneous compositions observed on the surface of Mercury can be explained by the melting of a chondritic mantle at different depths extending at least to 55 km and relatively high temperatures comprised between 1300 and 1550 °C with 10 to 45 weight % of melting. Hence, it is not required to invoke several stages of differentiation and remelting processes to explain the Mercurian surficial compositions derived from MESSENGER results [2, 6]. Additional experimental work is underway and will provide better constraints on the effects of sulphur and pressure on the physical and chemical properties of the Mercurian mantle.

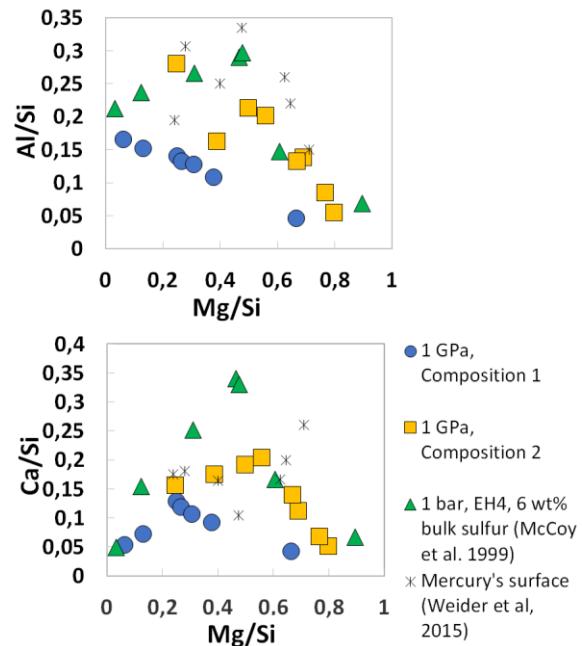
#### 4. Tables

Table 1: Starting compositions used in our experiments. The concentrations of all other elements than S and Si are similar than in EH4 enstatite chondrites [10].

Composition 1	Composition 2
62/38 silicate/metal	50/50 silicate/metal
5 wt% Si in metal	12 wt% Si in metal
59 wt% $\text{SiO}_2$ in silicate	50 wt% $\text{SiO}_2$ in silicate
2 wt% bulk S	6 wt% bulk S

#### 6. Figures

Figure 1: Comparison between Al/Si, Mg/Si and Ca/Si ratios of Mercury's surface (asterix) [7,11] with the melting products of enstatite chondrites (1 GPa this study, blue circles and yellow squares and 1 bar from [9], green triangles).



#### References

- [1] McClintock W. E. et al., Science, Vol. 321, pp. 62-65, 2008.
- [2] Nittler L. R. et al., Science, Vol. 333, pp. 847-1850, 2011.
- [3] Zolotov M. Y. et al., JGR, Vol. 118, pp. 138-146, 2013.
- [4] Head J. W. et al., Science, Vol. 333, pp. 1853-1856, 2011.
- [5] Smith D. E. et al., Science, Vol. 336, pp. 214-217, 2012.
- [6] Vander-Kaaden K. E. and McCubbin F., JGR, Vol. 120, pp. 195-209, 2015.
- [7] Weider S. Z. et al., EPSL, Vol. 416, pp. 109-120, 2015.
- [8] Charlier B. et al., EPSL, Vol. 363, pp. 50-60, 2013.
- [9] McCoy T. J. et al., Meteoritics & Planet. Sci., Vol. 34, pp. 735-746, 1999.
- [10] Wiik H. B., GCA, Vol. 9, pp. 279-289, 1956.
- [11] Namur O. et al., LPSC abstract 1309, 16-20 May 2015, The Woodlands, USA.